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TECHNICAL REPORT NO. 3-642

REVIEW OF SOILS DESIGN, CONSTRUCTION AND PERFORMANCE OBSERVATIONS OVERBANK STRUCTURE, OLD RIVER CONTROL

APPENDIX B: PUMPING TESTS AND WELL CLEANING OPERATIONS, 1969-1970

by

C. C. Trahan, R. L. Montgomery

October 1971

Sponsored by The President, Mississippi River Commission

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS

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FOREWORD

This is the second appendix to one of a series of reports on foundation and soil mechanics features of recently completed flood-control and navigation structures in the U. S. Army Engineer Division, Lower Mississippi Valley, Corps of Engineers. These studies are being conducted for the Engineering Division of the Mississippi River Commission (MRC), Corps of Engineers, by the U. S. Army Engineer Waterways Experiment Station (WES).

The overbank structure for Old River Control was designed by MRC and built under the supervision of the U. S. Army Engineer District, New Orleans (NOD), La. Geological studies, foundation investigations, and soil design studies were made by WES. Engineering measurement devices were installed and observations were made by NOD. Details of the above-listed studies are given in the basic report. A description and analysis of pumping tests and well cleaning operations on relief wells during May and June 1966 are presented in Appendix A, published in January 1968.

This appendix presents a description of well cleaning operations and pumping tests conducted in 1969 at the overbank structure. The well pumping test data are analyzed to compare the yields of the pump-tested wells with the yields obtained after installation.

The 1969 pumping tests were conducted under the supervision of Mr. A. L. Mathews (retired), and the borehole TV camera photographs were obtained under the supervision of Mr. J. L. Gatz. The data were analyzed and this appendix was prepared by Messrs. C. C. Trahan and R. L. Montgomery under the direction of Messrs. J. P. Sale, W. C. Sherman, and C. L. McAnear, Soils Division, WES.

COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of the WES during the conduct of this investigation and preparation of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
pints (U. S. liquid)	0.473179	cubic decimeters
pounds	0.45359237	kilograms
pounds per square foot	4.88243	kilograms per square meter
pounds per cubic foot	16.0185	kilograms per cubic meter
gallons (U. S. liquid) per minute	3.785412	cubic decimeters per minute

SUMMARY

This appendix is the second in a series presenting the results of tests performed at intervals of several years on the relief wells at the overbank structure, Old River Control, near Natchez, Miss. The tests reported herein were performed in 1969 and 1970 by the U. S. Army Engineer Waterways Experiment Station (WES) and included well pumping tests, analysis of well water samples, inspection of well screens with a borehole TV camera, and well sounding and cleaning operations. These tests were conducted to determine the decrease in efficiency of the relief wells since the latest pumping tests were conducted (1966) and since installation of the wells in 1957. Renovation attempts on four of the wells using chemical treatments and surging were not effective.

A borehole TV camera was used to inspect several of the well screens prior to and after pumping and cleaning operations. Generally, the well screens appeared to be in excellent condition before pumping and cleaning. Very little sand or gravel was found in the slots of the screens except in well 11, where the screen was about 50 percent clogged with filter material. There were no noticeable chemical or biological deposits on the interiors of the screens.

Chemical analyses of the water samples indicated that conditions are favorable for the buildup of incrustation in the wells. Also, it is quite possible that iron bacteria exist in the wells, as all the water samples contained relatively large amounts of iron. Although the water in the wells is somewhat corrosive, this condition is not considered an adverse factor for the wooden well screens.

Initial 1969-70 pumping tests on the wells indicated an average specific yield of 33 percent of the original yield. After cleaning by surging, the specific yield increased to an average of 50 percent of the original yield. The rate of sand infiltration during pumping was insignificant.

The effectiveness of the relief well system in reducing uplift pressures was computed using factors of safety with respect to uplift and taking into account the measured head loss through well filters and screens. The computed factor of safety was 1.9 before cleaning and 2.4 after cleaning. These values are about the same as those computed after the wells were cleaned in 1966. In the original design, the computed factor of safety at the ends of the well system was 3.3. Initially, WES reviewed the soils and foundation design studies for the overbank structure and evaluated observations made during and after construction. The review was published in the basic report, which contains a detailed description of the structure, foundation conditions, and relief well system.

REVIEW OF SOILS DESIGN, CONSTRUCTION

AND PERFORMANCE OBSERVATIONS

OVERBANK STRUCTURE, OLD RIVER CONTROL

APPENDIX B: PUMPING TESTS AND WELL CLEANING OPERATIONS, 1969-70

PART I: INTRODUCTION

Description of Structure

1. The overbank structure, located on the west bank of the Mississippi River approximately 35 miles* south of Natchez, Miss., is a reinforced concrete spillway with hinged timber-gate panels for control of flood flows. It is a major element in the plan for Old River Control. The structure has a gross length of 3356 ft and contains 73 gate bays, each having a 44-ft clear opening between 2-ft-thick bridge piers. The basic report** contains a detailed description of the structure, foundation conditions, and relief well system.

Relief Wells

2. Pressure relief wells were installed behind the overbank structure during the period April to August 1957 to reduce hydrostatic pressures in the sands beneath the structure during high water periods. The well system was designed so that a minimum factor of safety of at least 1.5 against uplift would be realized beneath or immediately downstream of the stilling basin during periods of high water. In the design of the system, there was assumed to be (a) an effective source of seepage entry 1500 ft

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

** U. S. Army Engineer Waterways Experiment Station, CE, "Review of Soils Design, Construction, and Performance Observations, Overbank Structure, Old River Control," Technical Report No. 3-642, Feb 1964, Vicksburg, Miss.

riverward of the line of wells and (b) an infinite length of impervious topstratum landward of the structure.

Design

3. The wells were designed to penetrate approximately 50 percent of the aquifer. Nineteen wells spaced on 184-ft centers were required. The computed factors of safety with respect to uplift were 4.8 and 3.3 at the center and ends of the well system, respectively. The well system was designed to provide factors of safety well in excess of 1.5, as it was considered that some decrease in well efficiency would occur with time, and it would be difficult to install additional wells at a later date. The total flow from the relief wells was estimated to be about 7.3 gpm per ft of net head on the well system or 150 gpm per well for a project flood stage, assuming the permeability of the foundation sands to be 500×10^{-4} cm per sec.

4. The wells consist of 8-in.-ID wood well screens (with 1/8-in. slots) and 8-in.-ID wood riser pipes. The risers discharge through the downstream baffle blocks. The well outlets are provided with check valves to prevent backflow of muddy water into the wells. Details of the well and the specified gradation of the filter gravel around the screen are presented in the basic report.

Installation

5. Since the permeability of the aquifer was found to increase with depth, the wells were installed to penetrate about 60 percent of the actual depth of the aquifer to achieve an effective penetration of 50 percent. The nominal length of the screen sections varied from 56 to 64 ft, except for wells 16 through 19, which had nominal lengths varying from 76 to 104 ft. The latter wells are located between sta 38 and sta 44, where the base of the aquifer (Tertiary deposits) is as much as 80 ft deeper than elsewhere. Installation and initial pumping test data for the relief wells are shown in table B1.

Purpose of Pumping Tests

6. The overbank structure has not been subjected to a significant head since its completion; consequently, the wells have not flowed and

Table B1

Installation and Pumping Test Data for Relief Wells, 1957

Well	Location Station	Date of Installation	As-Installed Elevation, ft msl: Inside Bottom of Well	As-Installed Elevation, ft msl: Top of Well Screen	As-Installed Elevation, ft msl: Top of Filter	Pumping Test Data: Date	Pumping Test Data: Specific Yield gpm/ft	Pumping Test Data: Rate of Sand Infiltration pt/hr
1	10+48	8/5	-69.84	-11.99	-1.62	10/19	37	None
2	12+32	7/29	-65.70	-4.05	+6.00	10/18	41	Trace
3	14+16	7/18	-58.33	-4.24	+6.67	10/15	24	Trace
4	16+00	7/16	-58.64	-4.05	+6.80	10/14	38	Trace
5	17+84	7/9	-58.62	-4.02	+6.22	10/13	38	Trace
6	19+68	6/26	-62.29	-4.04	+6.00	10/12	48	Trace
7	21+52	6/19	-66.83	-12.12	-1.80	10/10	20	Trace
8	23+36	6/14	-66.59	-11.93	-1.50	6/15	45	Trace
9	25+20	6/12	-70.65	-15.97	-6.00	10/9	27	Trace
10	27+04	6/10	-66.17	-3.79	+6.50	6/19	55	Trace
11	28+88	5/29	-65.46	-3.73	+6.50	6/18	47	Trace
12	30+72	5/27	-65.48	-3.76	+6.50	6/1	61	Trace
13	32+57	5/24	-69.73	-8.05	+3.00	5/25	48	Trace
14	34+40	5/19	-82.04	-28.01	-15.34	5/31	51	Trace
15	36+24	5/14	-93.90	-32.10	-19.70	5/15	76	0.04
16	38+08	4/23	-101.36	-28.01	-16.20	4/25	68	0.08
17	39+92	4/16	-120.67	-20.28	+10.37	4/17	85	Trace
18	41+76	4/19	-120.65	-20.25	-7.50	4/20	94	Trace
19	43+60	4/8	-121.33	-20.63	-9.00	4/15	92	Trace

Note: All wells located 57 ft landward of center line of structure.

their effectiveness under operating conditions has not been demonstrated. Recommendations were made in the basic report that pumping tests be conducted periodically on selected wells to determine if the wells had decreased in efficiency since their installation. In May 1965, pumping tests were conducted by the U. S. Army Engineer District, New Orleans (NOD), on wells 1, 4, 8, 10, 12, 15, and 18. Results of the tests indicated that the efficiency of these wells had decreased considerably since their installation; their specific yields were from 5 to 59 percent of their original specific yields. Consequently, in May and June 1966, personnel of the U. S. Army Engineer Waterways Experiment Station (WES) pump-tested and cleaned all wells by surging. Results presented in Appendix A* indicated that the specific yields of the wells before they were cleaned varied from 0 to 71 percent of the original specific yields and averaged about 34 percent. After the wells had been cleaned, their specific yields varied from 6 to 87 percent of their original specific yields and averaged 47 percent.

7. In July 1969 and April 1970, WES again pump-tested and cleaned all wells by surging. Four of the wells were also cleaned with different cleaning agents, and samples were obtained from selected wells for chemical analyses. Results of the pumping and cleaning operations and chemical analyses are presented in this appendix.

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* U. S. Army Engineer Waterways Experiment Station, CE, "Review of Soils Design, Construction, and Performance Observations, Overbank Structure, Old River Control, Appendix A: Pumping Tests and Well Cleaning Operations, 1966," Technical Report No. 3-642, Jan 1968, Vicksburg, Miss.

PART II: ANALYSES OF WATER SAMPLES

Method of Sampling

8. Water samples were obtained from wells 3, 6, 12, and 17 before well pumping tests were conducted. Representative water samples were obtained from one-quarter, one-half, and three-quarter depths and at the bottom of each well. These samples were designated as samples A, B, C, and D, respectively. The water sampler used for collecting the samples was developed at WES and is shown in fig. B1. The sampler consisted of a 2-ft-long by 4-in.-OD Plexiglas cylinder. A 4-in.-long by 3-1/2-in.-diam plastic piston mounted with two O-rings, which formed an effective seal while the piston was in motion, rode inside the cylinder. An air hose was attached to the top portion of the cylinder, and a spring release valve and a draw valve were attached to the bottom of the cylinder. An iron weight was attached to the bottom of the sampler to provide sufficient ballast to counteract the buoyancy of the samples. To obtain a water sample, a positive pressure was applied by a hand pump to the piston, driving it to the bottom of the sampler. This pressure, which was slightly greater than the hydrostatic pressure at the point at which the water sample was to be taken, was maintained while the sampler was lowered, by hand, to the desired depth. The positive pressure was then released, allowing water to enter the sampler. In a few instances, a vacuum was applied to the piston to overcome the friction between the piston and the inside walls of the cylinder. The sampler was then raised, by hand, out of the well. A small-diameter, 18-in.-long, clear, flexible-rubber tube was attached to the drain valve; the tube was then placed at the bottom of a 1-liter, clear-plastic sample container, the drain valve opened, and a small positive pressure reapplied to the top of the piston to force the water out of the sampler into the sample container. Each sample was identified and prepared for shipment to WES for testing.

Field Analyses

9. During the water sampling operations, observations were made as

Fig. B1. WES-designed water sampler

to the color, clarity, and odor of each sample. Generally, a blackish tint, caused by the presence of brownish-black particles suspended in the water, was noted in the samples. All the samples had a slight odor of the creosote used in treating the wood well screens prior to installation. Each sample was tested in the field for hydrogen ion concentration (pH) and dissolved oxygen (O_2). These tests were made in the field to obtain values that represented the true chemical character of the groundwater. The pH was determined using a color disk and pH indicator. A dissolved oxygen meter was used to make field determinations of O_2 content of the water samples.

Laboratory Analyses

10. Chemical tests were made on 16 water samples from the selected depths in relief wells 3, 6, 12, and 17. Total solids and alkalinity were determined on the samples as received. Calcium, magnesium, iron, and manganese contents were determined on portions of the original water samples, which were first treated with hydrochloric acid and boiled to dissolve all acid-soluble matter and then filtered. Certain silicates, silts, and organic matter were not dissolved by this treatment. The soluble silica (SiO_2) content was determined on the filtered as-received water samples.

Results

11. The results of field determinations and chemical analyses are given in table B2. The total solids increased significantly with depth in each well except well 12.

12. The pH values of the well samples were generally slightly acid, with values ranging from 6.4 to 7.1. There was no significant variation of these values with depth, although the samples from the shallow depths had the highest pH values in each case. The alkalinity, reported both in parts per million (ppm) as $CaCO_3$ and in equivalents per million (epm), generally increased with depth.

13. The epm hardness values, which were calculated based on the

Table B2

Analysis of Water Samples (1969)

		Field Determinations						Laboratory Determination of Chemical Constituents in ppm							epm		Specific Conductance	
Sample	Depth ft	Color	Clarity	Odor	Temp °C	pH	Oxygen ppm*	Total Soluble Iron	Mn	Ca	Mg	$SiSO_2$	Alka-linity C_aCO_3	Total Solids	Hard-ness	Alka-linity	10^{-6} mho/cm^3	Temp °C
								Well No. 3										
A	26.5	None	Murky	Creosote	22.7	7.1	2.0	2.8	0.5	106	10	18	280	448	6.15	5.60	663	23.8
B	53.8	None	Murky	Creosote	22.6	6.5	2.3	4.8	0.6	92	25	18	341	538	6.66	6.81	687	23.9
C	79.3	Blackish	Murky	Creosote	21.8	6.5	1.7	1.7	0.8	100	56	29	363	592	9.63	7.25	862	23.9
D	104.3	Blackish	Murky	Creosote	21.8	6.5	1.7	3.3	0.8	103	52	30	364	710	9.45	7.28	500	23.8
								Well No. 6										
A	27.5	None	Murky	Creosote	25.6	6.5	2.2	2.5	0.7	87	31	35	211	540	6.90	4.21	667	24.0
B	55.0	Blackish	Murky	Creosote	22.5	6.4	2.0	2.2	0.7	95	30	33	212	552	7.20	4.23	667	24.1
C	82.3	Blackish	Murky	Creosote	22.3	6.4	1.7	3.4	0.5	95	30	34	227	556	7.23	4.54	704	24.0
D	108.3	Blackish	Murky	Creosote	22.0	6.4	1.5	6.1	0.5	106	31	32	253	654	7.82	5.05	753	23.8
								Well No. 12										
A	28.3	None	Clear	Creosote	23.5	6.9	2.5	1.1	0.6	43	6	22	166	298	2.62	3.32	417	23.8
B	56.5	None	Clear	Creosote	24.0	6.5	2.0	0.9	0.7	117	50	34	410	678	9.95	8.19	918	23.8
C	84.6	None	Clear	Creosote	22.3	6.5	2.5	7.0	1.0	90	62	43	218	652	9.56	4.36	769	23.9
D	111.5	None	Clear	Creosote	22.0	6.5	2.5	5.6	0.5	87	22	39	226	644	6.15	4.51	847	23.8
								Well No. 17										
A	42.1	None	Murky	Creosote	21.6	7.0	1.8	1.9	0.2	39	7	10	132	318	2.52	2.64	372	23.9
B	84.1	Blackish	Murky	Creosote	21.4	6.7	1.7	6.1	0.5	65	14	15	196	444	4.42	3.91	500	24.0
C	126.2	Blackish	Murky	Creosote	21.6	6.8	1.8	4.6	0.5	75	17	20	221	430	5.14	4.42	543	23.9
D	166.7	Blackish	Murky	Creosote	20.7	6.7	1.3	8.0	0.9	93	60	17	268	506	9.63	5.36	625	23.9

* Temperatures exceeded range of calibration chart for the dissolved oxygen meter. The values shown were extrapolated.

calcium and magnesium determinations, indicated that the water in the wells was moderately hard to hard. Hardness generally increased with depth. Appreciable amounts of calcium and magnesium were found in all the water samples.

14. The chemical analyses made on water samples in 1966 and 1969 indicated significant amounts of iron in the wells. The quantities shown in table B2 represent total soluble iron in the water. This includes ferrous and ferric iron. With the exception of well 3, iron content in the wells increased with depth.

PART III: INSPECTION AND SOUNDING OF WELLS

Inspection of Well Outlets and Check Valves

15. The well outlet and check valve of each well were inspected before pumping and cleaning operations were performed on the wells. The outlets were all found to be in good condition. The check valves also were in good working condition; the rubber gaskets showed no signs of deterioration.

Sounding of Wells

16. Prior to testing, each well was sounded to determine the amount of sediment in the well. The sounding was made by measuring the distance from the top of the riser in the baffle block to the top of the sediment in the well using a steel tape attached to a sounding weight. After the initial sounding was made, the depth of the well was carefully measured with drill rods. A wood auger was attached to the bottom of the drill rods, and the rods were rotated until the auger penetrated the sediment in the well and reached the wooden plug forming the bottom of the well. The well was sounded with a weighted tape before and after surging to determine the amount of material entering the well. A final sounding was made after cleaning and pumping of the well had been completed.

17. In the soundings made in 1966 and presented in Appendix A, the depths of the wells were estimated by subtracting the initial elevations of the bottoms of the wells from the assumed elevations of the tops of the baffles. The estimated depths were slightly in error. The corrected data for 1966 soundings using 1969-70 measurements are given in table B3.

18. Sounding data obtained in 1969-70 are shown in table B4. The thickness of sediment in the wells before pumping varied from 0.33 to 2.84 ft except for well 16, which had 4.20 ft of sediment. Wells 10 and 19 were not sounded after pumping and cleaning operations in 1966, and well 16 had not been previously sounded. For all other wells except well 17, little or no sediment entered between 1966 and 1969-70. At well 17, 1.36 ft of sediment accumulated in the bottom during this period.

Table B3

Corrected 1966 Well Sounding Data

Well	Sediment in Well in 1957 ft	Measured Depth of Well* ft	1966 Before Pumping Depth to Sediment ft	1966 Before Pumping Sediment in Well ft	1966 After Pumping Depth to Sediment ft	1966 After Pumping Sediment in Well ft
1	0.30	117.69	116.48	1.21	116.50	1.19
2	0.22	113.78	112.18	1.60	112.60	1.18
3	0.04	106.39	102.37	4.02	106.10	0.29
4	0.27	106.42	104.83	1.59	106.12	0.30
5	0.21	106.60	106.10	0.50	106.31	0.29
6	0.34	108.44	105.54	2.90	107.90	0.54
7	0.28	114.96	114.44	0.52	114.18	0.78
8	0.31	114.30	105.21	9.09	113.95	0.35
9	0.25	118.43	113.45	4.98	116.96	1.47
10	0.02	113.95	109.25	4.70	--	--
11	0.06	113.42	111.89	1.53	112.96	0.46
12	0.20	113.46	110.56	2.90	112.75	0.71
13	0.20	117.60	113.44	4.16	116.54	1.06
14	0.27	130.07	126.10	3.97	129.15	0.92
15	0.18	141.20	136.80	4.40	139.30	1.90
16**	0.15	149.45	--	--	--	--
17	0.42	168.66	159.31	9.35	167.18	1.48
18	0.46	168,13	165.91	2.22	167.05	1.08
19	0.18	167.28	167.47†	--	--	--

* Depths of wells as measured in 1969 and 1970.

** In 1966, an obstruction was found in well 16 at a depth of about 21 ft, and soundings could not be made.

† Probable error in sounding.

Table B4

1969-70 Well Sounding Data

		1969-70 Data				Sediment Entering Well
		Before Pumping		After Pumping		
Well	Measured Depth of Well, ft	Depth to Sediment ft	Sediment in Well ft	Depth to Sediment ft	Sediment in Well ft	Between 1966 and 1969-70 ft
1	117.69	116.50	1.19	117.40	0.29	0.00
2	113.78	112.50	1.28	113.55	0.23	0.10
3	106.39	106.06	0.33	106.22	0.17	0.04
4	106.42	106.05	0.37	106.21	0.21	0.07
5	106.60	106.27	0.33	106.37	0.23	0.04
6	108.44	107.85	0.59	108.16	0.28	0.05
7	114.96	113.78	1.18	114.70	0.26	0.40
8	114.30	113.90	0.40	114.06	0.24	0.05
9	118.43	116.73	1.70	117.45	0.98	0.23
10	113.95	112.46	1.49	113.70	0.25	--
11	113.42	112.96	0.46	113.05	0.37	0.00
12	113.46	112.70	0.76	112.96	0.50	0.05
13	117.60	116.55	1.05	117.21	0.39	0.00*
14	130.07	128.79	1.28	129.43	0.64	0.36
15	141.20	139.29	1.91	139.40	1.80	0.01
16	149.45	145.25	4.20	146.05	3.40	--
17	168.66	165.82	2.84	166.10	2.56	1.36
18	168.13	166.97	1.16	167.35	0.78	0.08
19	167.28	166.52	0.76	166.71	0.57	--

* Sediment in well 13 decreased by 0.01 ft.

19. Well 16 had not been pump-tested prior to 1970 because an obstruction was found in the well in 1966 at a depth of about 21 ft. When the well was sounded with drill rods in April 1970, the obstruction was no longer at that elevation. Instead, an obstruction was found at a depth of 146 ft. The auger was able to penetrate through the obstruction and continued to a depth of 149.4 ft, which was assumed to be the bottom of the well. From additional probing with the drill rods, it appeared that there was a considerable amount of wood debris in the bottom of the well. Pieces of wood, some 3 in. in diameter by 1/4 in. thick and some 3/4 by 3/4 by 2-1/2 in., were also found at the bottom of well 17. It did not appear that the wood came from the wood well screens since this would undoubtedly have caused a considerable intake of sediment. The sediment measured in these wells was not appreciable.

Well Screen Inspection

20. A closed-circuit television (TV) system was used to examine the well screens of wells 3, 6, 11, and 15 before and after cleaning operations to determine the nature of any clogging. The apparatus consisted of an Eastman International Borehole Telescope FB-400 (Borehole TV). The probe, containing a TV camera, was lowered into each well on a cable, and pictures of the well interior were transmitted to a TV screen. The TV screen was photographed to provide a record of observations. Generally, the well screens were in good condition with very little sand or gravel in the slots. The slots in well 11 appeared to be about 50 percent clogged with gravel or sand. Although cleaning operations in this well appreciably increased the specific yield, there was no apparent change in the amount of sand and gravel in the slots. The TV camera revealed no evidence of chemical deposits on the interiors of the well screens.

PART IV: WELL PUMPING AND CLEANING OPERATIONS

River Stages

21. Wells 11 through 19 were pump-tested and cleaned from 10 July to 11 August 1969. During this period, the Mississippi River rose from el 35.7* to a maximum elevation of 39.2 on 25 July, then dropped to el 27.2 on August 11. Pumping and cleaning operations had to be discontinued on 11 August because the water level in the well was too low to permit pumping. The remaining wells (1 through 10) were pump-tested and cleaned from 2 April to 17 April 1970, during which time the Mississippi River stage varied from el 34.7 to el 40.5.

Pumping and Cleaning Operations

22. The wells were pump-tested and cleaned consecutively, starting with well 19 on the east end of the structure. Equipment used for the pumping and cleaning operations was essentially the same as that described in Appendix A. Each well was first pump-tested to determine its specific yield. Generally, this initial test was conducted at three different drawdowns. The well was then cleaned by five or six cycles of surging, each cycle consisting of 15 round trips with a surging block. The well was pumped at a rate of 45 gpm as it was being surged. Material in the well was removed with a bailer after each surging cycle. A second pumping test was conducted on the well after it had been cleaned. If the second test showed that surging had significantly increased the specific yield, the well was cleaned again with two or three surging cycles and retested. All operations were completed on one well before moving to the next well.

23. After the above-mentioned cleaning and pumping operations had been performed on all wells, additional cleaning operations were performed on four wells (3, 6, 11, and 15) to determine which of three chemical treatments was most effective in cleaning the wells. Also, well 2 was

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* All elevations (el) cited herein are in feet referred to mean sea level.

pumped continuously for 8 hr to determine whether the well produced sand at a rate greater than 2 pt/hr after 8 hr of pumping.

Test Results

Pumping tests

24. A summary of pumping test data collected in 1969 and 1970 is shown in table B5. Plots of observed discharge versus drawdown are shown in plates B1-B5. Also shown in the plots are similar data for the original pumping tests made in 1957 and for the final pumping tests made in 1966. Fig. B2 is a comparison of the computed specific yields from the 1969-70 pumping tests with those computed from previous pumping tests. Before the wells were cleaned in 1969-70, their specific yields varied from 0 to 76 percent of their original specific yields and averaged about 33 percent. After the wells had been cleaned, their specific yields varied from 19 to 84 percent of their original specific yields and averaged about 50 percent. In 1966, the specific yields of the wells before they were cleaned averaged 34 percent of their original specific yields. After the wells were cleaned, their specific yields averaged 47 percent of their original specific yields. It can be noted then that the average specific yield of the wells before they were cleaned in 1969-70 was about the same as the average specific yield before they were cleaned in 1966. Also, after the wells were cleaned in 1969-70, their average specific yield was only slightly higher than it was after the wells were cleaned in 1966.

Additional cleaning

25. Special well cleaning operations were performed on wells 3, 6, 11, and 15 to determine the effectiveness of three different cleaning agents. In well 3, 30 lb of a mildly alkaline commercial detergent was placed in the well. The well was then surged with one cycle and the detergent was allowed to remain in the well overnight. The next day, the well was surged with three cycles with the surging block and then pump-tested to determine its specific yield. The same procedure was repeated on well 11 using a household cleaner, sodium bisulfate, and on well 15 using a strong alkaline detergent, trisodium phosphate. Results of the pumping tests,

Table B5

1969-1970 Pumping Tests and Surging Data

Well	Date	River Stage ft msl	Pumping Data: Discharge gpm	Pumping Data: Drawdown in Well ft	Pumping Data: Specific Yield gpm/ft	Pumping Data: Rate of Sand Infiltration pt/hr	Surging Data: No. of Surging Cycles*	Surging Data: Material Entering Well ft**	Surging Data: Discharge While Surging gpm
1	16 Apr 1970	40.1	83	3	28	--	--	--	--
	16 Apr 1970	40.1	165	6	28	--	--	--	--
	16 Apr 1970	40.1	242	9	27	Trace	--	--	--
	17 Apr 1970	40.5	--	--	--	--	6	0.68	45
	17 Apr 1970	40.5	252	9	28	Trace	--	--	--
	17 Apr 1970	40.5	--	--	--	--	3	0.41	45
	17 Apr 1970	40.5	254	9	28	Trace	--	--	--
2	15 Apr 1970	39.8	102	4	26	--	--	--	--
	15 Apr 1970	39.8	151	6	25	--	--	--	--
	15 Apr 1970	39.8	225	9	25	1.52	--	--	--
	15 Apr 1970	39.8	--	--	--	--	6	1.59	45
	16 Apr 1970	40.1	261	9	29	1.90	--	--	--
	16 Apr 1970	40.1	--	--	--	--	3	1.06	45
	16 Apr 1970	40.1	266	9	30	2.54	--	--	--
3	14 Apr 1970	39.5	97	15	6	0.0	--	--	--
	14 Apr 1970	39.5	--	--	--	0.0	6	0.54	45
	14 Apr 1970	39.5	230	15	15	0.0	--	--	--
	14 Apr 1970	39.5	--	--	--	0.0	3	0.41	45
	14 Apr 1970	39.5	236	14	17	Trace	--	--	--
	29 Apr 1970(1)	41.3	--	--	--	--	3	0.70	--
	29 Apr 1970	41.3	263	15	18	--	--	--	--
4	13 Apr 1970	39.1	65	3	22	--	--	--	--
	13 Apr 1970	39.1	130	6	22	--	--	--	--
	13 Apr 1970	39.1	192	9	21	0.0	--	--	--
	13 Apr 1970	39.1	--	--	--	0.0	6	0.61	45
	13 Apr 1970	39.1	218	9	24	0.0	--	--	--
	13 Apr 1970	39.1	--	--	--	--	3	0.24	45
	14 Apr 1970	39.5	222	9	25	0.51	--	--	--
5	9 Apr 1970	35.8	110	4	28	--	--	--	--
	9 Apr 1970	35.8	228	8	28	--	--	--	--
	10 Apr 1970	35.8	293	10	29	0.0	--	--	--
	10 Apr 1970	35.8	--	--	--	--	5	0.64	45
	10 Apr 1970	35.8	317	10	32	Trace	--	--	--
6	8 Apr 1970	35.3	0†	--	0	--	--	--	--
	9 Apr 1970	35.8	--	--	--	--	6	0.52	45
	9 Apr 1970	35.8	84	13	6	0.0	--	--	--
	9 Apr 1970	35.8	--	--	--	--	3	0.32	45
	9 Apr 1970	35.8	97.5	13	7	Trace	--	--	--
	5 May 1970(2)	45.4	--	--	--	--	3	1.13	--
	5 May 1970	45.4	133	15	9	Trace	--	--	--
7	7 Apr 1970	35.1	29	15	2	0.0	--	--	--
	8 Apr 1970	35.3	--	--	--	--	6	0.51	45
	8 Apr 1970	35.3	154	13	12	Trace	--	--	--
	8 Apr 1970	35.3	--	--	--	--	3	0.24	45
	8 Apr 1970	35.3	180	13	14	Trace	--	--	--
8	6 Apr 1970	35.0	28	6	5	--	--	--	--
	6 Apr 1970	35.0	50	9	6	--	--	--	--
	6 Apr 1970	35.0	77	12	6	0.0	--	--	--
	7 Apr 1970	35.1	--	--	--	--	5	0.83	40
	7 Apr 1970	35.1	188	12	16	0.0	--	--	--
	7 Apr 1970	35.1	--	--	--	--	3	0.51	40
	7 Apr 1970	35.1	210	12	18	0.0	--	--	--
9	3 Apr 1970	34.8	23	6	4	--	--	--	--
	3 Apr 1970	34.8	41	9.5	4	--	--	--	--
	3 Apr 1970	34.8	63	13	5	0.0	--	--	--
	3 Apr 1970	34.8	--	--	--	--	5	0.41	40
	6 Apr 1970	35.0	144	12	12	0.0	--	--	--
	6 Apr 1970	35.0	--	--	--	--	3	0.39	45
	6 Apr 1970	35.0	158	12	13	0.17	--	--	--
10	2 Apr 1970	34.7	77	3	26	--	--	--	--
	2 Apr 1970	34.7	154	6	26	--	--	--	--
	2 Apr 1970	34.7	230	9	26	0.0	--	--	--
	2 Apr 1970	34.7	--	--	--	--	5	0.56	45
	3 Apr 1970	34.7	255	9	28	0.0	--	--	--
11	8 Aug 1969	30.7	16	6	3	--	--	--	--
	8 Aug 1969	30.7	--	--	--	--	5	0.35	40
	8 Aug 1969	30.7	77	8	10	0.0	--	--	--
	8 Aug 1969	30.7	--	--	--	--	3	0.14	50
	11 Aug 1969	27.7	52	5	10	0.0	--	--	--
	30 Apr 1970(3)	42.1	--	--	--	--	3	1.08	--
	30 Apr 1970(3)	42.1	172	15	11	--	--	--	--
12	6 Aug 1969	32.8	66	3	22	--	--	--	--
	6 Aug 1969	32.6	131	6	22	--	--	--	--
	6 Aug 1969	32.1	210	9	23	0.0	--	--	--
	6 Aug 1969	32.1	--	--	--	--	5	0.65	50
	7 Aug 1969	31.5	219	9	24	0.0	--	--	--

(Continued)

Note: (1), well cleaned with detergent.
(2), well cleaned with trisodium phosphate.
(3), well cleaned with sodium bisulfate.
* One surging cycle consisted of 15 strokes with a surging block.
** Based on soundings before and after surging.
† Not enough flow to keep pump primed.

Table B5 (Concluded)

			Pumping Data				Surging Data		
Well	Date	River Stage ft msl	Discharge gpm	Drawdown in Well ft	Specific Yield gpm/ft	Rate of Sand Infiltration pt/hr	No. of Surging Cycles	Material Entering Well ft	Discharge While Surging gpm
13	4 Aug 1969	34.0	48	4	21	--	--	--	--
	4 Aug 1969	34.0	168	8	21	--	--	--	--
	5 Aug 1969	33.5	217	9.5	23	0.0	--	--	--
	5 Aug 1969	33.5	--	--	--	--	5	0.82	50
	5 Aug 1969	33.1	250	9	28	0.0	--	--	--
	5 Aug 1969	33.1	--	--	--	--	2	0.14	50
	6 Aug 1969	32.6	248	9	28	0.0	--	--	--
14	1 Aug 1969	36.2	41	4	10	--	--	--	--
	1 Aug 1969	36.2	89	8	11	--	--	--	--
	1 Aug 1969	36.2	139	12	12	0.0	--	--	--
	1 Aug 1969	36.2	--	--	--	--	5	0.70	50
	4 Aug 1969	34.5	218	12	18	0.0	--	--	--
	4 Aug 1969	34.5	--	--	--	--	2	0.06	50
	4 Aug 1969	34.5	190	10	19	0.0	--	--	--
15	30 July 1969	37.7	31	4	8	--	--	--	--
	30 July 1969	37.7	73	8	9	--	--	--	--
	30 July 1969	37.7	128	12	11	0.0	--	--	--
	31 July 1969	37.0	--	--	--	--	5	0.94	40
	31 July 1969	37.0	168	12	14	0.0	--	--	--
	31 July 1969	37.0	--	--	--	--	2	0.57	40
	31 July 1969	37.0	168	12	14	0.0	--	--	--
	1 May 1970(2)	43.1	--	--	--	--	3	1.05	--
	1 May 1970(2)	43.1	272	15	18	--	--	--	--
16	25 July 1969	39.2	37	4	9	--	--	--	--
	25 July 1969	39.2	70	8	9	--	--	--	--
	25 July 1969	39.2	95	12	8	1.15	--	--	--
	25 July 1969	39.2	--	--	--	--	5	0.11	50
	28 July 1969	38.8	219	12	18	0.51	--	--	--
	28 July 1969	38.8	--	--	--	--	3	0.86	50
	28 July 1969	38.8	282	12	24	Trace	--	--	--
	28 July 1969	38.8	--	--	--	--	3	0.06	50
	29 July 1969	38.2	314	12	26	Trace	--	--	--
	29 July 1969	38.2	--	--	--	--	3	--	50
	29 July 1969	38.2	232	8	29	Trace	--	--	--
17	17 July 1969	36.5	68	3	23	--	--	--	--
	17 July 1969	36.5	138	6	23	--	--	--	--
	17 July 1969	36.5	211	9	23	Trace	--	--	--
	17 July 1969	36.5	--	--	--	--	5	0.55	50
	18 July 1969	36.6	262	9	29	Trace	--	--	--
	18 July 1969	36.6	--	--	--	--	3	0.39	50
	22 July 1969	38.0	186	6	31	Trace	--	--	--
	22 July 1969	38.0	--	--	--	--	2	0.11	50
	22 July 1969	38.0	197	6	33	Trace	--	--	--
18	14 July 1969	36.0	118	2	59	--	--	--	--
	14 July 1969	36.0	228	4	57	--	--	--	--
	15 July 1969	36.2	335	6	56	Trace	--	--	--
	15 July 1969	36.2	--	--	--	--	5	0.79	50
	16 July 1969	36.3	338	6	56	--	--	--	--
	16 July 1969	36.3	--	--	--	--	3	0.32	50
	16 July 1969	36.3	339	6	56	0.9	--	--	--
19	10 July 1969	35.7	84	3	28	--	--	--	--
	10 July 1969	35.7	169	6	28	--	--	--	--
	10 July 1969	35.7	247	9	27	0.0	--	--	--
	11 July 1969	35.9	--	--	--	--	5	0.87	40
	11 July 1969	35.9	182	6	30	0.0	--	--	--
	14 July 1969	36.0	--	--	--	--	2	0.12	40
	14 July 1969	36.0	184	6	31	0.0	--	--	--

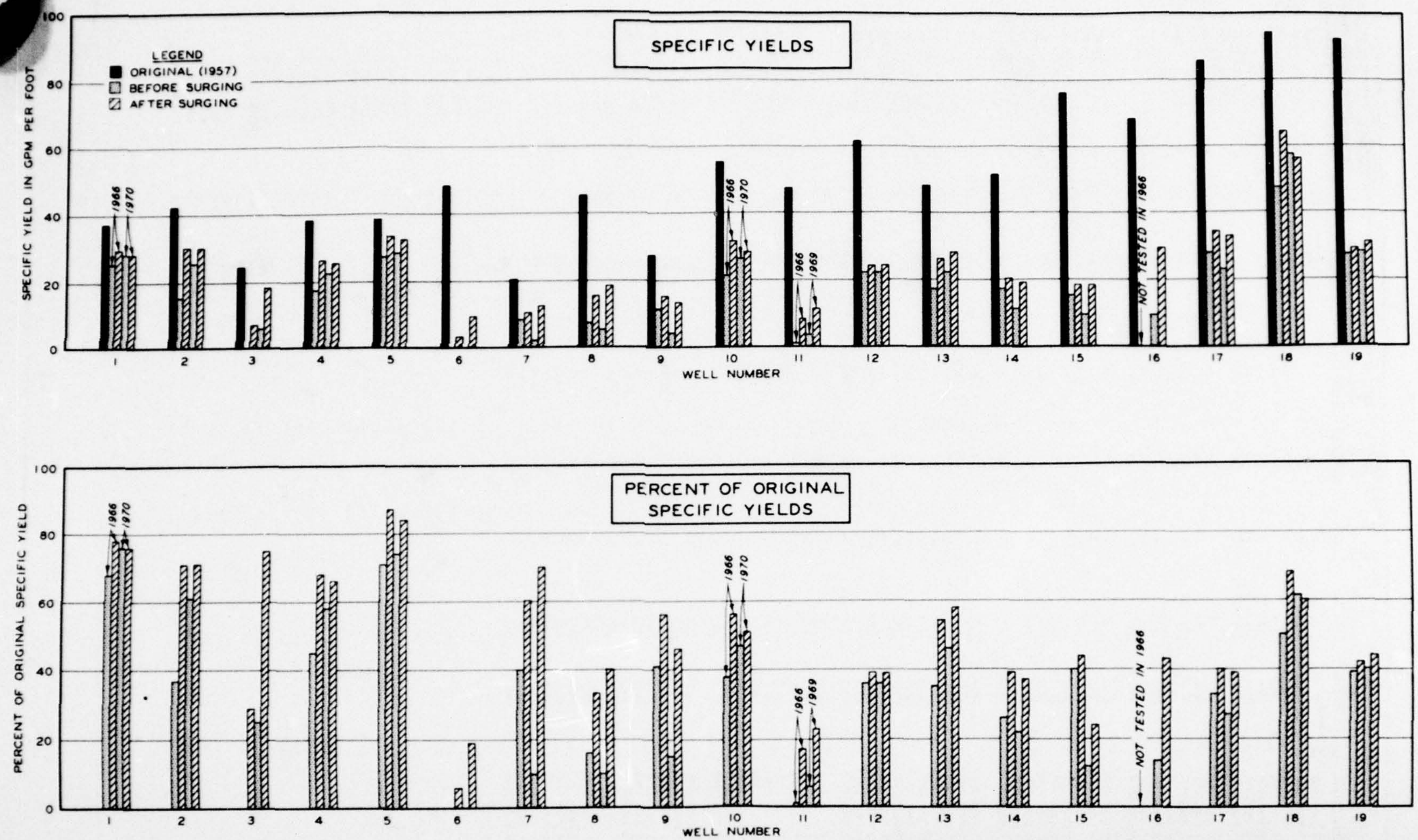


Fig. B2. Comparison of 1957, 1966, and 1969-70 specific yields

shown in table B6, indicated that the trisodium phosphate apparently produced the best results; therefore, the trisodium phosphate was used to clean well 6 in order to verify the results found in well 15. It can be seen in table B6 that cleaning of the wells with cleaning agents did not significantly increase the specific yields of the wells.

Sand infiltration

26. A well was considered stable when the rate of sand infiltration into the well was less than 2 pt/hr after the well had been pumped continuously for 8 hr. All of the wells except well 2 indicated negligible rates of sand infiltration during final pumping. Well 2 showed a rate of sand infiltration of 2.54 pt/hr for the final pumping test; therefore, the well was pumped continuously for 8 hr. After 1 hr and 20 min of continuous pumping, the measured rate of sand infiltration was 1.11 pt/hr. After approximately 8 hr of pumping, the rate of sand infiltration was only 0.2 pt/hr and the well was considered stable.

Effectiveness of Well System

27. The only reliable method of evaluating the effectiveness of the well system in reducing uplift pressures beneath the structure is to measure piezometric pressures in the sand aquifer beneath the structure when the structure is subjected to a high differential head. As the structure has not been subjected to any significant differential head since its completion, the significance of the reduction in specific yields of the wells was determined indirectly on the basis of the following assumptions:

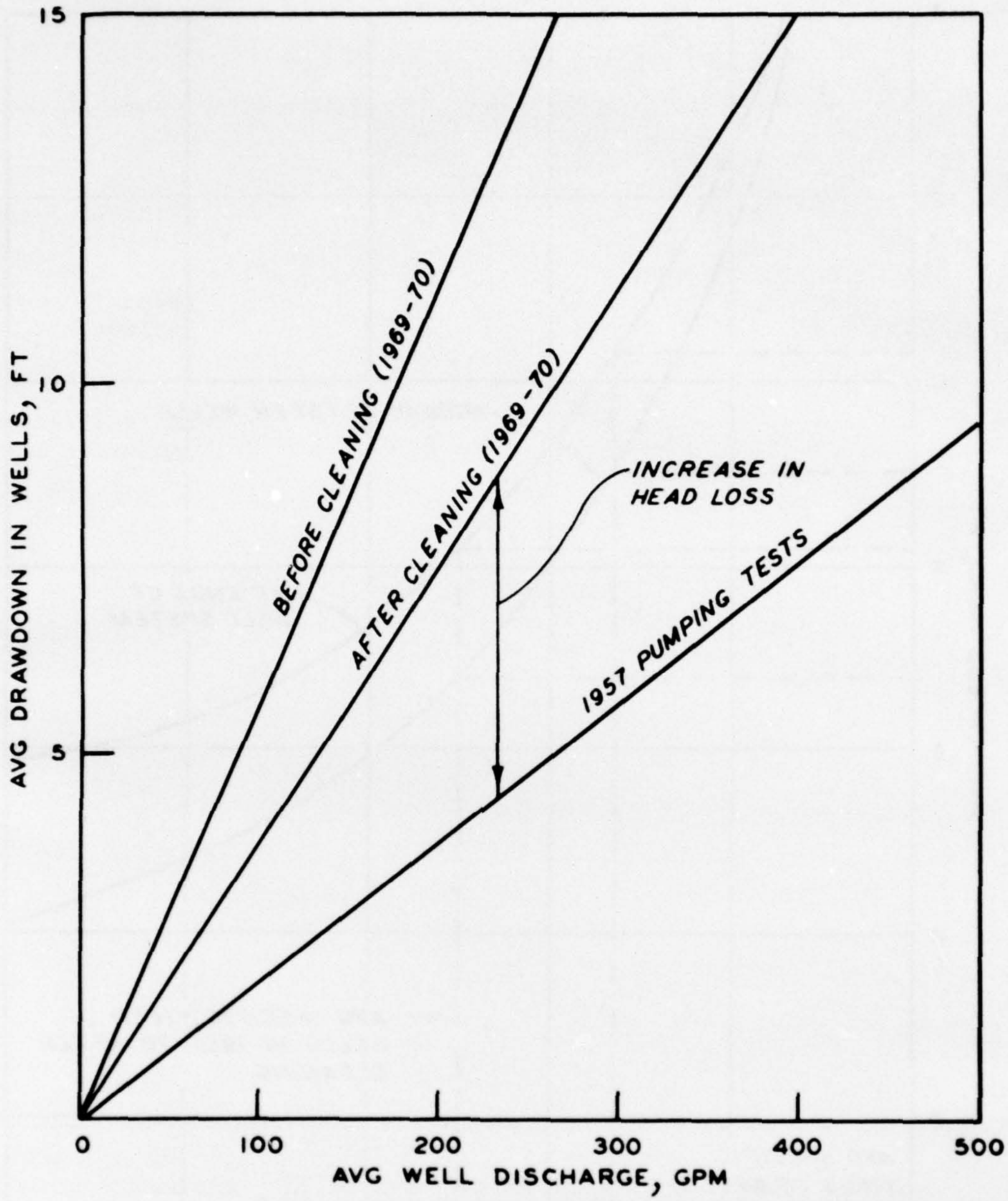
- a. The well system, as installed, was capable of reducing the uplift pressures to those values computed in design.
- b. The reductions in specific yields of the wells were due to increases in head loss through the well filters and screens.

The average increase in head loss of the well system since its installation in 1957 was estimated from the average specific yields in 1957 and in 1969-70, as shown in fig. B3. The increase in head loss in the wells was used to compute the excess heads shown in fig. B4. A summary of computed factors of safety against uplift is shown in table B7.

Table B6

Results of Pumping Tests After Additional Well Cleaning

Well	Cleaning Agent	Specific Yield, gpm/ft of Drawdown: Original (1957)	Before Cleaning (1969-70)	After Cleaning (1969-70)
3	Mild detergent	24	17	18
11	Sodium bisulphate	47	10	11
15	Trisodium phosphate	76	10	15
6	Trisodium phosphate	48	7	9



NOTE: AVG SPECIFIC YIELD OF WELLS FROM 1957 PUMPING TESTS = 52.3 GPM/FT DRAWDOWN.

AVG WELL EFFICIENCY FROM 1969-70 PUMPING TESTS

a) 33% OF 1957 SPECIFIC YIELD BEFORE WELLS CLEANED.

b) 50% OF 1957 SPECIFIC YIELD AFTER WELLS CLEANED.

Fig. B3. Head losses due to decrease in average well efficiency

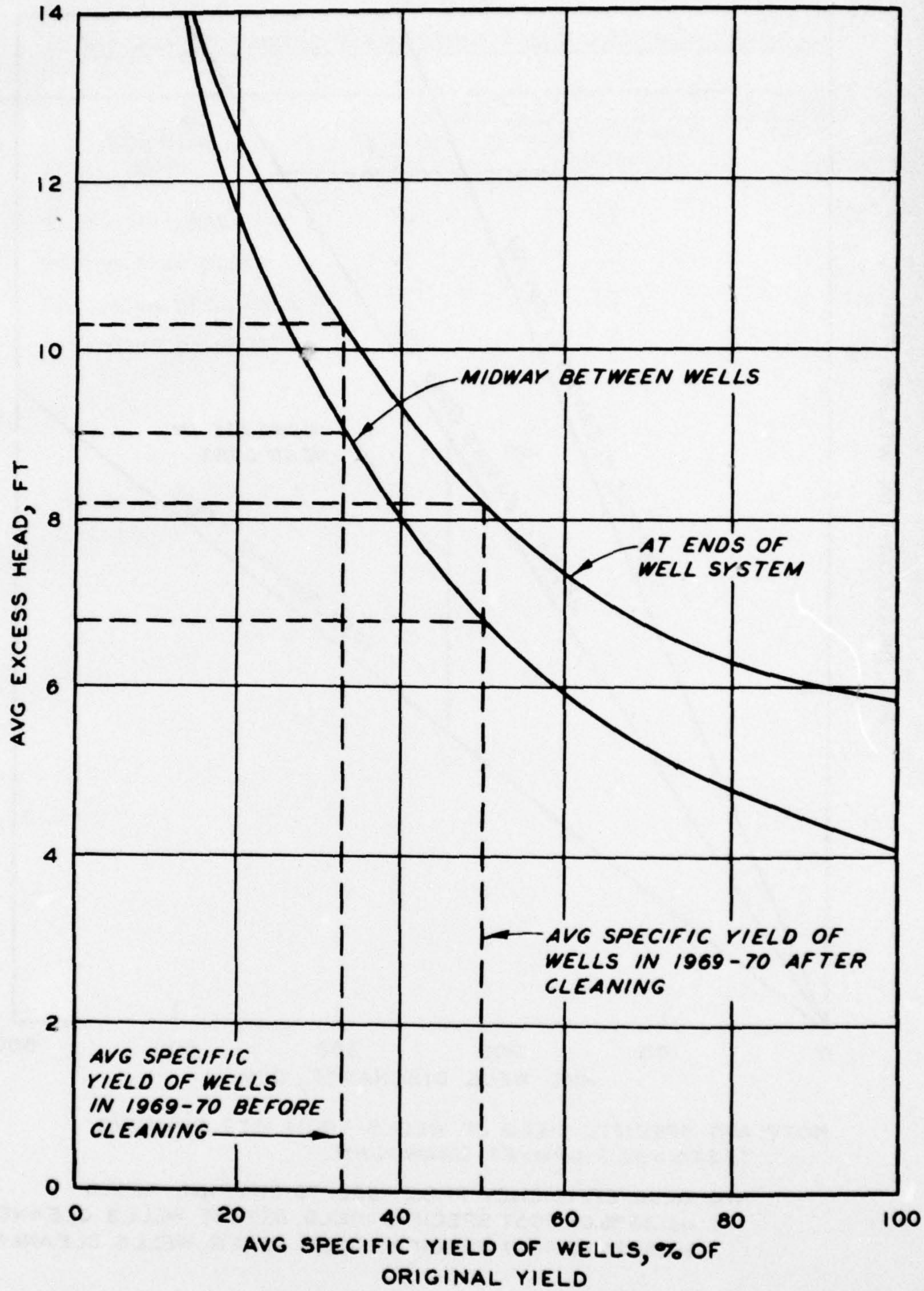


Fig. B4. Well efficiency versus excess head

Table B7

Summary of Factors of Safety

	Excess Head, ft*		Factor of Safety**	
	Midway	Edge	Midway	Edge
Original design	4.1	5.9	4.8	3.3
1966:				
Before cleaning	8.9	10.1	2.2	1.9
After cleaning	7.1	8.5	2.8	2.3
1969-70:				
Before cleaning	9.0	10.3	2.2	1.9
After cleaning	6.8	8.2	2.9	2.4

* From fig. B4.

** Factor of safety against uplift $= \dfrac{\text{Effective overburden at top of sand aquifer}}{\text{Excess head} \times \gamma_w}$

Effective overburden at top of sand aquifer:

Concrete slab	2.5 ft × 87.5 pcf =	219 psf
Filter	1.0 ft × 62.5 pcf =	63 psf
Clay	20.0 ft × 47.5 pcf =	950 psf
	Total	1232 psf

$$\therefore \text{FS} = \frac{1232}{\text{Excess head} \times \gamma_w}$$

28. The computed factors of safety with respect to uplift for the 1969-70 data were about the same as those computed for 1966. Before the wells were cleaned in 1969-70, the factors of safety midway between the wells and at the ends of the structure were 2.2 and 1.9, respectively; these values are still greater than the minimum factor of safety of 1.5 required in design. After the wells were cleaned, the factors of safety were 2.9 and 2.4. The factors of safety are thus considerably reduced from the values of 4.8 and 3.3 computed for the wells when they were installed.

PART V: DISCUSSION

29. The results of the 1966 and 1969-70 pumping tests indicated that all of the relief wells have experienced significant reductions in specific yields since their installation. Examination of four of the well screens with the TV borehole camera indicated no significant incrustation or clogging of the slots by filter material, with the exception of well 11.

30. Three different cleaning agents used in attempts to restore well efficiency in selected wells were ineffective. Trisodium phosphate treatments were only slightly more effective than the other two treatments. In the past, phosphates have been used to disperse iron hydroxide, iron oxide, and manganese hydroxide. The slight improvement in efficiency with the use of trisodium phosphate might suggest that reduction in efficiency is related to iron content in the well water. However, a firm conclusion cannot be made on this basis; therefore, it is important that the incrustating material be identified.

31. The three major causes of well incrustation are listed as follows in order of frequency of occurrence:* (a) incrustation from precipitation of carbonates of calcium and magnesium or their sulfates; (b) incrustation from precipitation of iron and manganese compounds (primarily their hydroxides or hydrated oxides); (c) stoppage due to slime produced by iron bacteria or other slime-forming organisms. Treatments have been developed for each of the three types of incrustations described and are used in present practice. Incrustation from calcium and magnesium carbonate that has cemented the gravel filter particles can be readily removed by the use of muriatic acid (hydrochloric, 27.92 percent acid). However, the acid will attack galvanized wire bound around the wood stave well screens. Iron oxides can be removed by treatments using polyphosphates and by surging the wells. A small amount of calcium hypochlorite should be used with the polyphosphate treatments to kill iron bacteria that may be present. Chlorine treatment of wells has been proven effective where clogging is caused by bacterial growths or slime.

---

* Ground Water and Wells, 1st Ed, Edward E. Johnson, Inc., St. Paul, Minnesota, 1966.

32. Chlorine may cause deterioration of the wood well screens in that the chemical destroys the lignin in the wood, resulting in a reduction in its structural strength. Other chemical treatments for incrustation in wells are presently commercially available. Although treatments have been established for various incrustants, the problem arises in the isolation of the incrustant or incrustants and utilizing the proper treatments to most effectively restore well yields.

33. The laboratory analyses in 1966 and 1969 on well water samples indicated that the well water is high in carbonate hardness and dissolved iron content. The high iron content of the well water is conducive to the growth of iron bacteria in the wells, although biological analyses were not made to substantiate existence of iron bacteria. Therefore, it is quite possible that conditions in the wells are favorable for formation of all three types of incrustations.

34. Generally, the material causing the clogging will be a mixture of several things, never a single substance.* The relative proportions of the various substances shown by chemical analyses of a sample of the incrustating materials would indicate the kind of treatment that would be effective in restoring well efficiencies. It is impractical to sample the gravel filters of these wells to investigate clogging materials. However, it would be a relatively simple operation to place samples of the filter materials in nylon bags at selected depths inside several of the wells for approximately one year. These samples could then be removed and subjected to chemical and biological analyses. If incrustating agents were found, then an effective treatment for restoring well yields could be developed.

---

* "The Corrosion and Incrustation of Well Screens," Bulletin No. 834, September 1955, Edward E. Johnson, Inc., St. Paul, Minnesota.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

35. On the basis of the tests and analyses presented herein, the following conclusions appear warranted:

a. The overall efficiency of the relief well system before cleaning in 1969 and 1970 was about the same as it was before cleaning in 1966. The factor of safety with respect to uplift before cleaning in 1969-70 was 1.9. Pumping and surging were only partially effective in restoring the well efficiencies. The average factor of safety is still well above the minimum design criterion of 1.5; however, because of the substantial reduction in specific yields of numerous wells and the extremely low yields in several wells, it is important that means be developed to restore well efficiencies or at least that measures be developed to prevent further reductions that might impair the structure.

b. The TV borehole camera revealed that the well screens were in excellent condition, with very little mechanical or chemical clogging of slots.

c. Analyses of water samples indicated that conditions are favorable for incrustations to form. The decrease in efficiency of the wells may be the result of precipitation of iron compounds, calcium carbonate, and similar incrustating materials or the result of jellylike slime from iron bacteria growth in the gravel filters. The nature of incrustations needs to be identified in order that appropriate cleaning agents can be determined.

d. All wells are considered stable in that sand infiltration during pumping was less than 2 pt/hr.

Recommendations

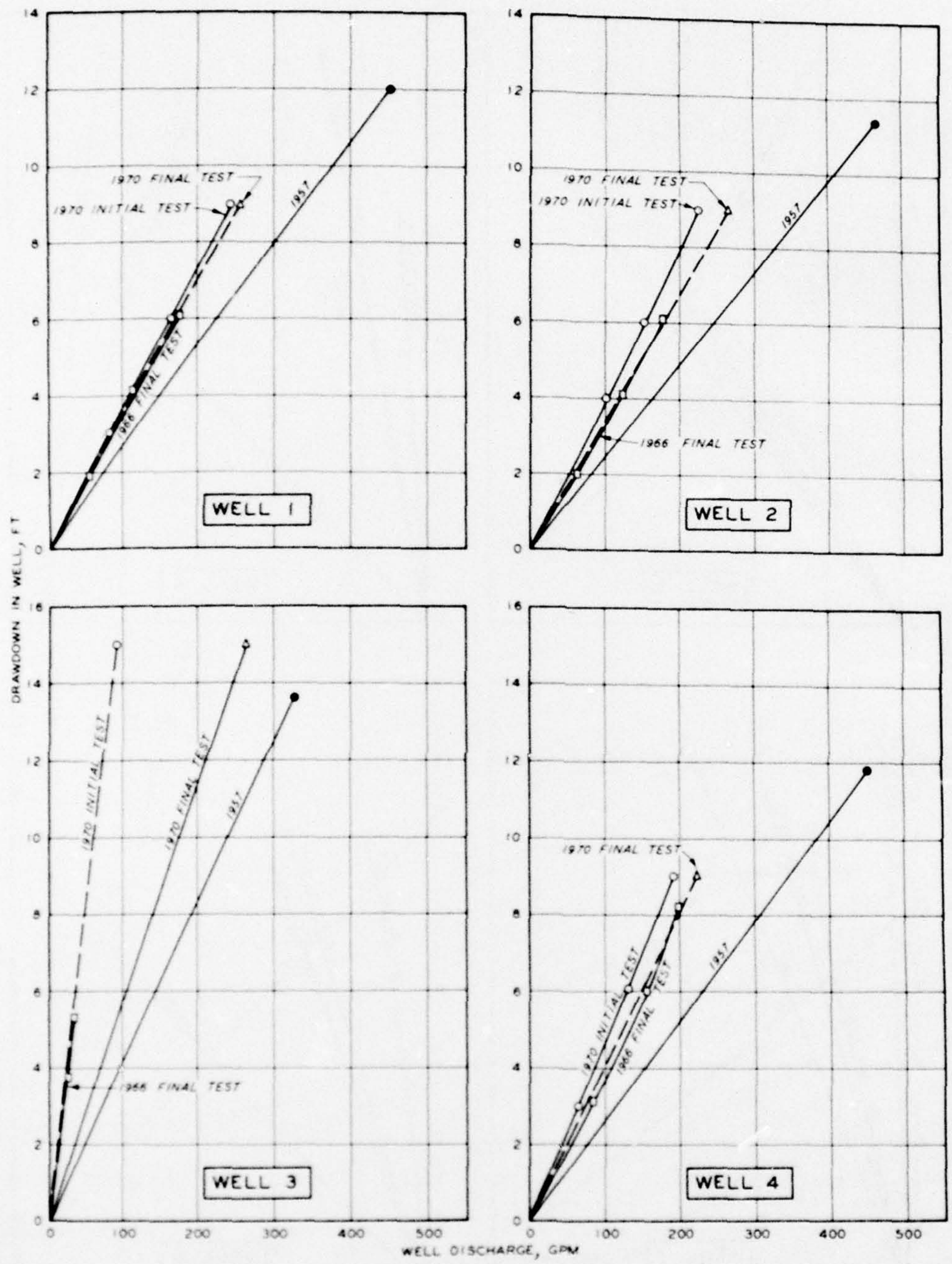
36. The following recommendations are made based on the analysis of data presented herein:

a. To provide information on well incrustants and growths, it is recommended that samples of the gravel filter be suspended at selected depths inside several of the wells for approximately one year. The gravel samples would then be removed and subjected to laboratory analyses to determine the nature of incrustants. This procedure is simple, inexpensive, and promising. Therefore, immediate implementation is recommended.

b. Well pumping tests and cleaning operations should continue for all wells at 2-yr intervals until improved well treatment techniques are developed and an appropriate maintenance program can be recommended.

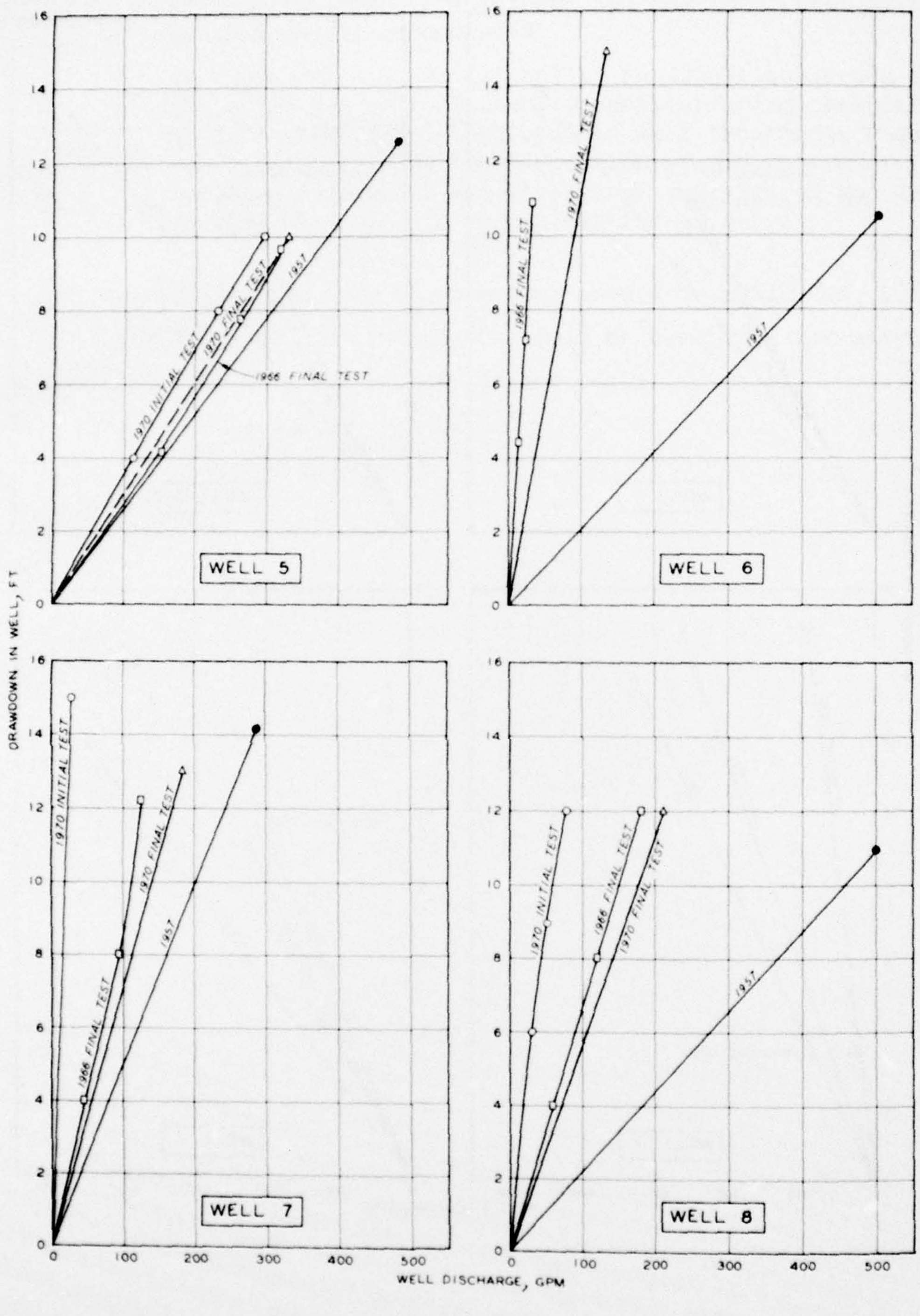
c. In 1972, wells 6, 8, 11, and 15 should be subjected to pumping tests and well cleaning operations using chemical and biocide treatments. Appropriate well treatments should be ascertained pending identification of the nature of incrustations by chemical and biological analysis of the gravel samples mentioned in recommendation a. above.

The effectiveness of each type of treatment should be evaluated, and the most promising treatment and technique should be developed for use in a well maintenance program for all the relief wells.



WELL DISCHARGE VS
MEASURED DRAWDOWN

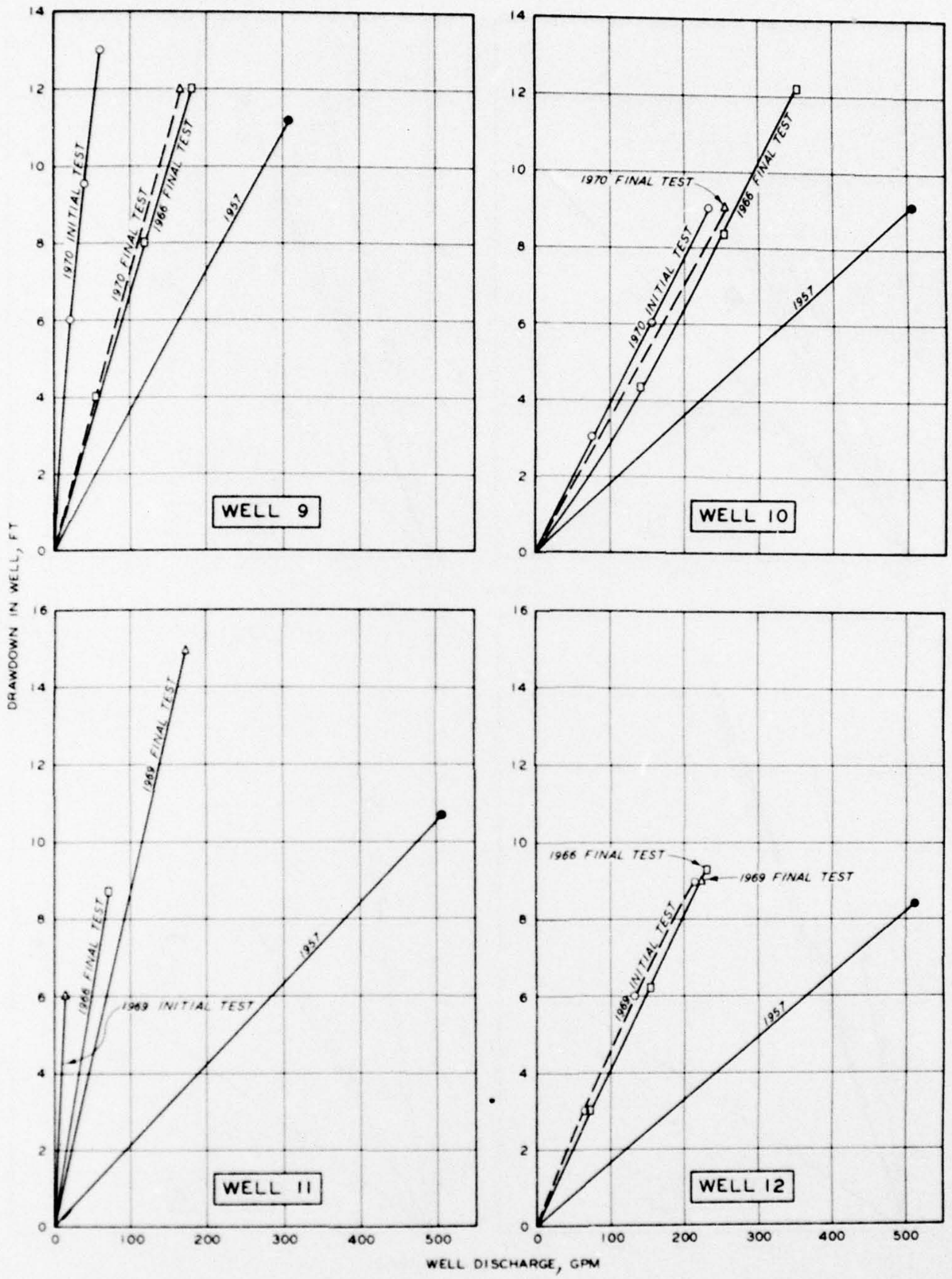
WELLS 1-4



WELL DISCHARGE VS
MEASURED DRAWDOWN

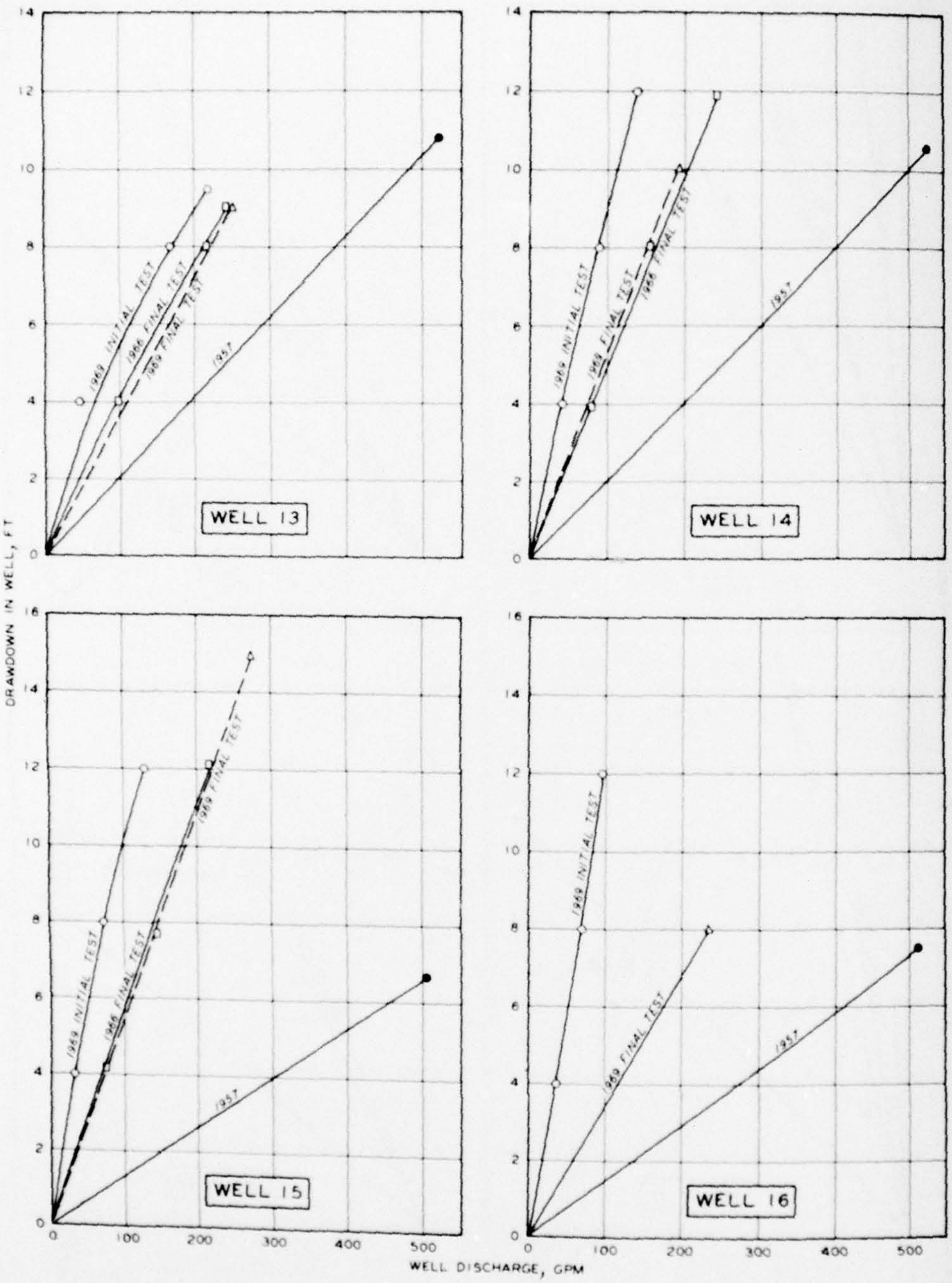
WELLS 5-8

PLATE B2



WELL DISCHARGE VS
MEASURED DRAWDOWN

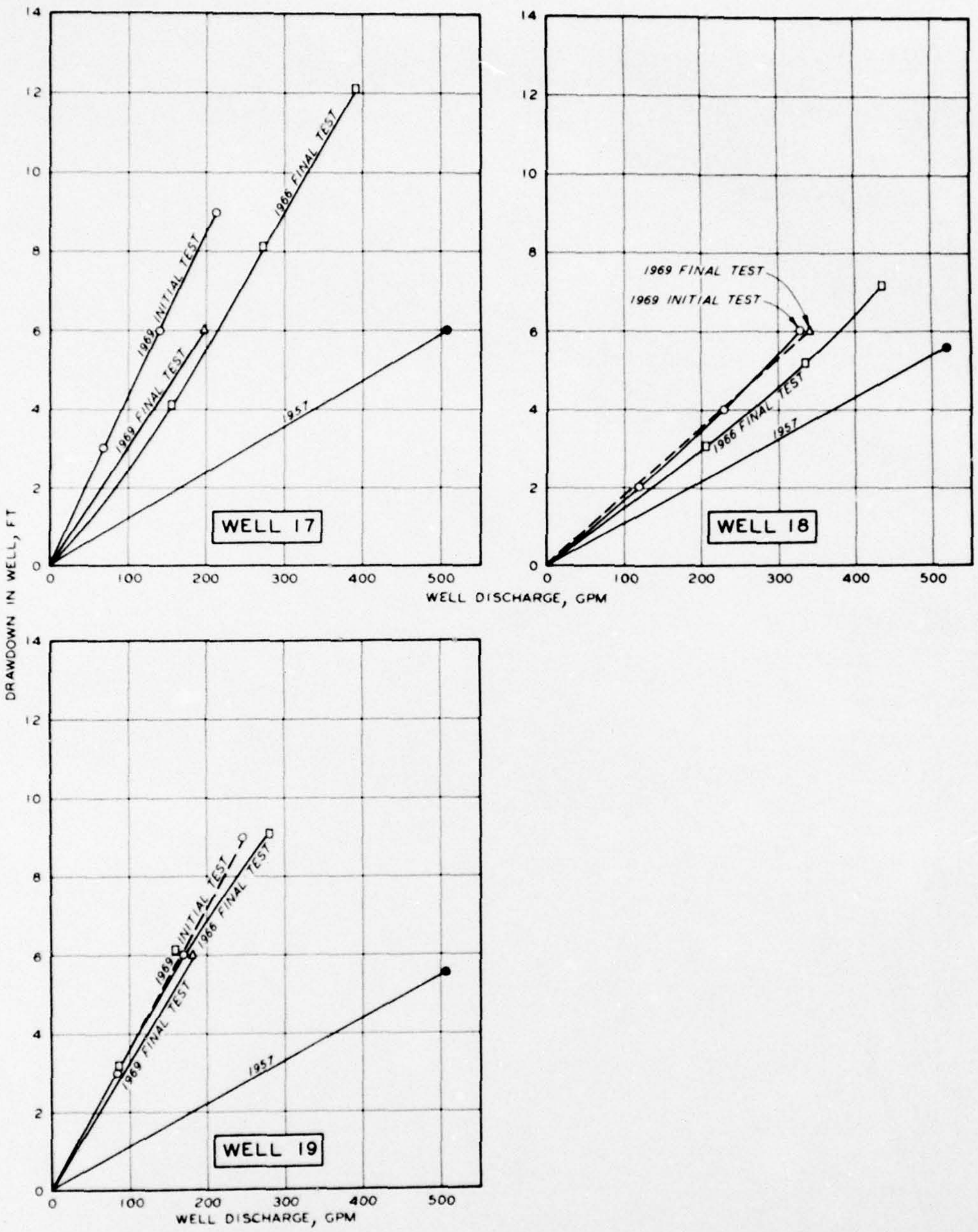
WELLS 9-12



WELL DISCHARGE VS
MEASURED DRAWDOWN

WELLS 13-16

PLATE B4



WELL DISCHARGE VS
MEASURED DRAWDOWN

WELLS 17-19

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	The President Mississippi River Commission Vicksburg, Miss.

13. ABSTRACT

This appendix is the second in a series presenting the results of tests performed at intervals of several years on the relief wells at the overbank structure, Old River Control, near Natchez, Miss. The tests reported herein were performed in 1969 and 1970 by the U. S. Army Engineer Waterways Experiment Station (WES) and included well pumping tests, analysis of well water samples, inspection of well screens with a borehole TV camera, and well sounding and cleaning operations. These tests were conducted to determine the decrease in efficiency of the relief wells since the latest pumping tests were conducted (1966) and since installation of the wells in 1957. Renovation attempts on four of the wells using chemical treatments and surging were not effective. A borehole TV camera was used to inspect several of the well screens prior to and after pumping and cleaning operations. Generally, the well screens appeared to be in excellent condition before pumping and cleaning. Very little sand or gravel was found in the slots of the screens except in well 11, where the screen was about 50 percent clogged with filter material. There were no noticeable chemical or biological deposits on the interiors of the screens. Chemical analyses of the water samples indicated that conditions are favorable for the buildup of incrustation in the wells. Also, it is quite possible that iron bacteria exist in the wells, as all the water samples contained relatively large amounts of iron. Although the water in the wells is somewhat corrosive, this condition is not considered an adverse factor for the wooden well screens. Initial 1969-70 pumping tests on the wells indicated an average specific yield of 33 percent of the original yield. After cleaning by surging, the specific yield increased to an average of 50 percent of the original yield. The rate of sand infiltration during pumping was insignificant. The effectiveness of the relief well system in reducing uplift pressures was computed using factors of safety with respect to uplift and taking into account the measured head loss through well filters and screens. The computed factor of safety was 1.9 before cleaning and 2.4 after cleaning. These values are about the same as those computed after the wells were cleaned in 1966. In the original design, the computed factor of safety at the ends of the well system was 3.3. Initially, WES reviewed the soils and foundation design studies for the overbank structure and evaluated observations made during and after construction. The review was published in the basic report, which contains a detailed description of the structure, foundation conditions, and relief well system.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Borehole TV cameras						
Old River Control Structure						
Overbank Structure						
Pumping tests (wells)						
Relief wells						
Well screens						

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